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PROPOSITION DE SUJET DE THESE

Intitulé : End-to-end design of unconventional lens and a multi-tasks neural network

Référence : **TIS-DTIS-2024-32**
(à rappeler dans toute correspondance)

Début de la thèse : Octobre 2024	**Date limite de candidature :** Juillet 2024

Mots clés

Optical and processing joint design, optics, machine learning, deep learning

Profil et compétences recherchées

Master in machine learning and/or computer vision, knowledge in optics will be appreciated

Présentation du projet doctoral, contexte et objectif

The images captured by a camera are usually processed using algorithms which are more and more often based on neural networks. The lens parameters must then to be optimized in order to increase the performance of this processing, sometimes regardless of the image quality at the output of the optics. This raises the question of the end-to-end optimization of a camera dedicated to a given processing with a neural network. This question has recently led to a new field of research on the joint design of lens and neural network [1-5]. The general idea is to model the image, as captured by a given sensor, with a differentiable model with respect to the lens parameters. Thus, gradient descent optimization tools can be used to jointly optimize the optical and the neural network parameters. In this context, several fields of application have been investigated in the literature, such as depth of focus extension [1,4,5], depth estimation [2], pose estimation while preserving privacy[3] or object detection[2].

ONERA has been working on the end-to-end design of lenses and neural networks for several years. Our work is based on the use of a differentiable optical model based on ray tracing (Formidable). This model takes as input an optical system defined by a set of lenses and simulates its impulse response as well as its Jacobian with respect to the lens parameters. Using this tool, we have performed the joint design of the lens parameters for a single task such as image restoration [4,5]. However this work only considered optimization of refractive lenses. On the other hand, previous works of the literature on end-to-end joint design of optics and processing have proposed to use unconventional lenses such as phase mask or a free-form lens to encode the lens impulse response for a dedicated unsupervised or supervised processing [1,2,6,7]. These unconventional lenses have been introduced in a joint optical/neural network joint design, but only with a simple optical model based on Fourier's optics[1,2]. Therefore the first aim of this thesis is to integrate the optimization of unconventional lenses such as phase masks or freeform lenses into the end-to-end joint optical and neural network optimization framework, using a ray tracing optical model such as Formidable. In particular, an important work will be to investigate the interaction between the choice of the neural network architecture and the unconventional surface type.

On the other hand, multi-tasks approaches are increasingly being developed in the computer vision literature, e.g. for RGB-D cameras producing both depth maps and extended depth-of-field images[8], or for aerial image processing for depth maps and image segmentation [9]. Furthermore, in the field of joint optical and neural processing joint design, two tasks can be trained in an adversarial mode, as in camera designed to perform image analysis while preserving privacy [3]. The joint optimization of an unconventional lens with two neural networks, possibly in a competitive mode, or in interaction with each other, is another important issue to be investigated in the thesis. This objective raises several questions, such as how to deal with the necessary balance between the two tasks during the optimization and how to avoid the local optima for the lens parameters associated with each task. It also questions the chosen starting points for each part of the system.

The PhD will be organized as follows : after studying the bibliography on end-to-end joint design of optics and processing, including neural networks, the PhD student will develop new optimization tools to perform the joint design of unconventional lenses and neural networks using Formidable. This work will be done in collaboration with the ONERA/DOTA department. Secondly, the addition of another task to the joint optimization framework will be considered, either in a multi-task mode, or in an adversarial mode. The last

part of the thesis will be dedicated to the realization of a demonstrator for a selected application.

Bibliography

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[4] A. Halé et al., “End-to-end sensor and neural network design using differential ray tracing. Optics express, 29(21), 2021.

[5] M. Dufraisse et al., (2023). Deblur or denoise: the role of an aperture in lens and neural network co-design. *Optics Letters*, *48*(2), 231-234.

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Collaborations envisagées

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